Temperatures in the Sugarbush

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Most maple producers are keenly aware of the weather during the spring, with temperature the most frequently observed parameter. One major limitation to the sap-run forecasting ability of many producers is that measurement of air temperature in one location does not capture the wide variation in air temperature throughout the sugarbush; nor does it accurately reflect the temperature of the diverse parts of trees, or of the soil. A study of the range of temperatures in the forest during sugaring time is helpful in understanding some of the influences of weather on sap flow. This article briefly summarizes a large set of data collected over the past years which includes many sugarbush temperatures, and will give a few examples of the sometimes unexpected variation in temperatures which occur during the spring.

The temperature data referenced in this article were all collected at the Univeristy of Vermont Proctor Maple Research Center in Underhill Center, Vermont, over the past decade. Temperature measurement is part of an ongoing effort to describe sap pressure and flow in sugar maple in relation to weather. Some of the data can be seen live during the spring at http://www.uvm.edu/~pmrc --- click on TREEMET. Measurements were made with copper/constantan thermocouples, which provide a high degree of accuracy, and were recorded every 15 minutes around the clock by remote dataloggers.

The sap flow mechanism of sugar maple requires periods of freezing and thawing; freezing temperatures produce negative pressure in the tree and result in water uptake from the soil, while thawing results in positive pressure that causes flow from tapholes. Large limbs and tree trunks respond slowly to changes in temperature, so that when alternating cold nights and warm days lead to periods of sap flow, this is caused primarily by temperatures low and sustained enough to freeze small branches, and warm enough to thaw them. Predicting when branches will freeze is not always easy, because air temperature measured close to the ground may not be a good indication of the temperature in the tree canopy, particularly in the absence of air movement. Figure 1 shows temperatures at different heights measured on successive nights in 2006. On April 2, wind speeds averaged 7-10 mph, which provided good air mixing, and temperatures at different heights were all within 1.5 degrees F, with the coldest air above. A short period below 32 degrees caused small branches to freeze, providing a “recharge” through the sap flow mechanism, and consequent sap flow by the following mid-day.

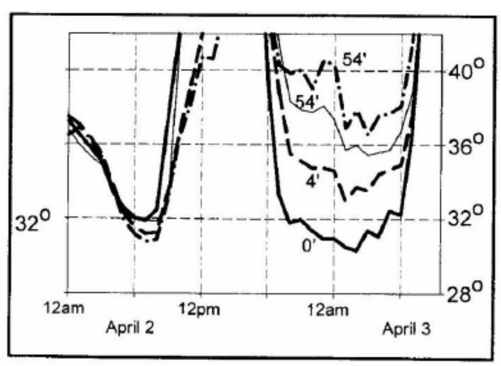

Figure 1: Air temperature at different heights (heavy lines) and branch temperature (thin line) on successive nights in April, 2006.

On April 3, wind speeds had diminished to less than 2 mph, and a temperature gradient of about 8 degrees from the ground surface to mid-canopy at 54' was present, as the heavier cold air sank to the lowest point. Puddles on the ground froze, but the temperatures above this were too warm to freeze the branches. Still nights during the spring were more common than windy nights; for example, during the sugaring seasons of 2005 and 2006, about 60% of the nights were calm enough to establish a vertical temperature gradient similar to April 3. Additionally, still nights allow cold air to move downslope and pool in low spots, so that higher parts of the sugarbush might not receive frosts that occur in hollows.

Another sugarbush incongruity is the temperature of small branches and twigs: they are rarely the same as the air surrounding them, as can be seen in figure 2. In sunlight, the dark bark absorbs much of the sun's radiation, so that during a cloudless period, the branch is commonly 8-10 F degrees warmer than the air.

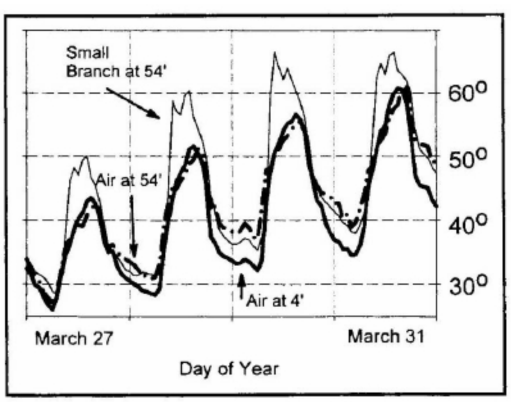

Figure 2: Air temperature at two heights and branch temperature on four days in March, 2006.

When the branch is already thawed, this heating of the wood causes a temporary increase in sap pressure, in part from evolution and expansion of gas bubbles, as well from osmotic forces, leading to a greater rate of sap flow from a taphole. Often during a sap run, the sap pressure, and consequent sap flow rate, oscillates from night to day (i.e. it is higher during the day and lower at night) without any frost due to the changing temperature of the branches. Please note, however, that gas bubble expansion is a secondary mechanism of sap pressurization in maple; the principal cause of pressurization is water uptake into wood cells during freezing, followed by a thaw. While the heating of the branches temporarily increases the rate of sap flow, it also diminishes sap pressure over the course of the sap run because water is constantly evaporating through the thin bark of the branches. Thus the strength of a sap run that continues for several days without a frost may vary with the rising and falling temperature, but it will eventually diminish to a slow trickle due to evaporative losses from branches, which will eliminate all of the pressure in the system over time. So, warm and sunny days during the sugaring season are both a blessing and a curse to syrup producers.

Another anomaly, which can occur any time of the year, is a phenomenon known as black-body radiation. This often occurs on calm nights, where branches (and other solid objects) lose heat into the atmosphere when the sky is clear; in branches this results in a temperature about 1 degree F lower than the surrounding air, which can been seen on the still night of April 2-3 in Figure 1.

Data from thermocouples located at different depths in tree trunks show that the wood is almost never at a uniform temperature, and during the sugaring season this non-uniformity can affect sap flow, particularly when part of the tree is frozen. Deeper into the tree, the wood is buffered from air temperature, so that freezing and thawing occur much more gradually than in small branches. During the summer, the center of the trunk is usually the coolest portion of the tree during the day, with the wood temperature closer to air temperature nearer the surface. Because the trunk is often shaded in the forest, a strong temperature gradient from the north to south side is rarely present. In the winter, the whole trunk eventually freezes; with warmer days in the spring it slowly thaws from the outside toward the center, with the south side thawing sooner. At shallow depths the wood is constantly warming and cooling in response to the air temperature, in a complex manner, but it may take many days or weeks for the center of a large tree to thaw. Data from the past 3 years show that large trees may be partially frozen during a portion of the sugaring season: complete thawing of two 24"+ diameter trees at the Proctor Center occurred on March 1 in 2004, March 28 in 2005 and March 30 in 2006. Figure 3, from 2006, shows a period when the air temperature was ideal for sap flow,

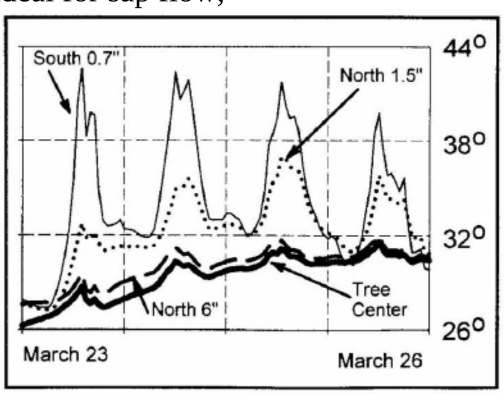

Figure 3: Variation in tree trunk temperature at different depths and aspects on four days in March, 2006.

with daytime highs in the mid 40's after a week of below-freezing temperatures.While the outer portion of both the north and south sides of the trunk was warm enough for sap to flow, a significant portion of the trunk was frozen. With this large reservoir unavailable, sap flow during the period March 23-26 was minimal.

Thawing of the trunk may make more sap and sugar available in the early spring, but as the season progresses, heating speeds microbial growth which leads a reduction in flow from a taphole. Data from a depth of 2-3" at taphole height indicate that when the wood reaches about 50 degrees for more than a day or two, the flow from a nearby hole begins to diminish. This is evident when comparing flow and wood temperatures from the south side vs. the north side of the trunk.

Finally, soil temperature is unlike air temperature at most times. Like tree trunks, soils are buffered from the extremes of air temperature, with the deeper layers cooler in the summer and warmer in the winter. Over the course of a typical year, at a depth of 12 inches, the temperature varies from about 35-65 degrees. The largest fluctuations occur after the snow has melted and before the leaves shade the ground; during the summer soil temperature is quite stable. In 10 years of measurements at different depths, soils in the forest at the Proctor Maple Research Center have almost never been observed to freeze. In the forest, a layer of fresh leaves, as well as decomposing leaf litter, contains many air spaces which act as insulation for the soil beneath it. In addition, uncompacted snow is a superb insulator; at 1400' on the side of a mountain, our research site usually has snow cover between November and late March. Without snow, soils would freeze with possible negative consequences to sap flow and tree vigor, as demonstrated by an experiment from New Brunswick[1]. In the 1990's, researchers kept snow from forest plots and compared the soil temperature and sap flow to control plots with normal snow accumulation. With no snow cover, soil temperatures at 8" depth were as low as 21 degrees F in February, and sap yield for the following spring was less than 50% of control trees. Deep soil freezing was also implicated as a contributing cause to maple dieback in Quebec during the 1980's. Although producers have no influence over snowfall, soil compaction by logging equipment, or other traffic, and snow removal for roads could result in a loss of the natural insulation that protects the shallow roots of maple, and impact the sap season for nearby trees.

[1]Robitalle, G., Boutin, R. and D. Lachance. 1995. Effects of soil freezing stress on sap flow and sugar content of mature sugar maples. Can. J. For. Res. 25: 577-587.